those around its equator and still better than in those at its constant posterior pole. The diffusion or extension of the primordial visual apparatus of the protozoan grade such as is seen in Euglena, is a result merely, in Volvox, of the permanent attainment of the colonial grade of development which has ended in a sort of blastula-like form, each cell of which is provided with a sense organ. In other words we have in Volvox a blastula-like type with a sensory apparatus apparently developed at its anterior pole, while at its posterior pole this sensory apparatus is so little developed as to be nearly absent, possibly owing to disuse. The degree of development of this supposed sensiferous apparatus at opposite poles in Volvox stands in an obvious relation to the respective importance of such a contrivance at those poles in relation to the welfare of the organism. It is probable that, if what I have here described is really a visual or other sensory apparatus, it is the most primitive and unspecialized compound sensiferous organ yet detected in the living world. At any rate it is probably to be regarded as a compound organ in the same sense that the retina and ommatidia of other and higher forms are to be regarded as compound organs in that they are cellular aggregates. The further study of these remarkable structures and relations in Volvox is desirable, and as the organism is accessible to many students it is to be hoped that such study may not be long delayed, and that not only a more careful study of the minute structure of the "eye-spots" may be carried out, but also that figures will be produced which will give adequate prominence to the most important of the facts which I have here attempted to put upon record.

THE DEVELOPMENT OF THE THEORIES OF CRYSTAL STRUCTURE.[1]

IN 1822, the Abbé Haüy[2] declared that since all crystals of the same substance, whatever their external form, may be

[1] Abstracted by. W. S. Bayley from an article by H. A. Miers in *Nature* of January 17, 1889.

[2] "Traité de Cristallographie." (Paris, 1822.)

reduced by cleavage to the same solid figure, this cleavage solid has the form of the ultimate particles into which any crystal may, in imagination, be separated by repeated subdivision, and that this is, therefore, the form of the structural unit, although not necessarily that of the chemical molecule. Hence a crystal is to be regarded as constructed of polyhedral particles, having the form of the cleavage fragment, placed beside one another in parallel positions. A crystal of salt, for example, which naturally cleaves parallel to the faces of the cube, is constructed of cubic particles.

Upon the relative dimensions of the structural unit depends the form assumed by the crystals of a given substance.

This theory not only accounts for the existence of cleavage, but further defines the faces which may occur upon crystals of a substance having a given cleavage figure; for, if once it is assumed that a crystal-face is formed by a series of the particles whose centres lie in a plane, it follows that all such planes obey the well-known law which governs the relative positions of crystal-faces.

A natural advance was made from the theory of Haüy, without detracting from its generality, by supposing each polyhedral particle in Haüy's system to be condensed into a point at its centre of mass, so that the positions of the molecules, and therefore of the crystalline planes, remain the same as before; but the space occupied by a crystal is now filled, not by a continuous structure resembling brickwork, but by a system of separate points.

In such a system of points, if the straight line joining any pair be produced indefinately in both directions, it will carry particles of the system at equal intervals along its entire length; in other words, all the structural molecules of a crystal must lie at equal distances from each other along straight lines. The interval between particles along one straight line will, in general, be different from those along another, but the molecular intervals along parallel straight lines will always be the same.

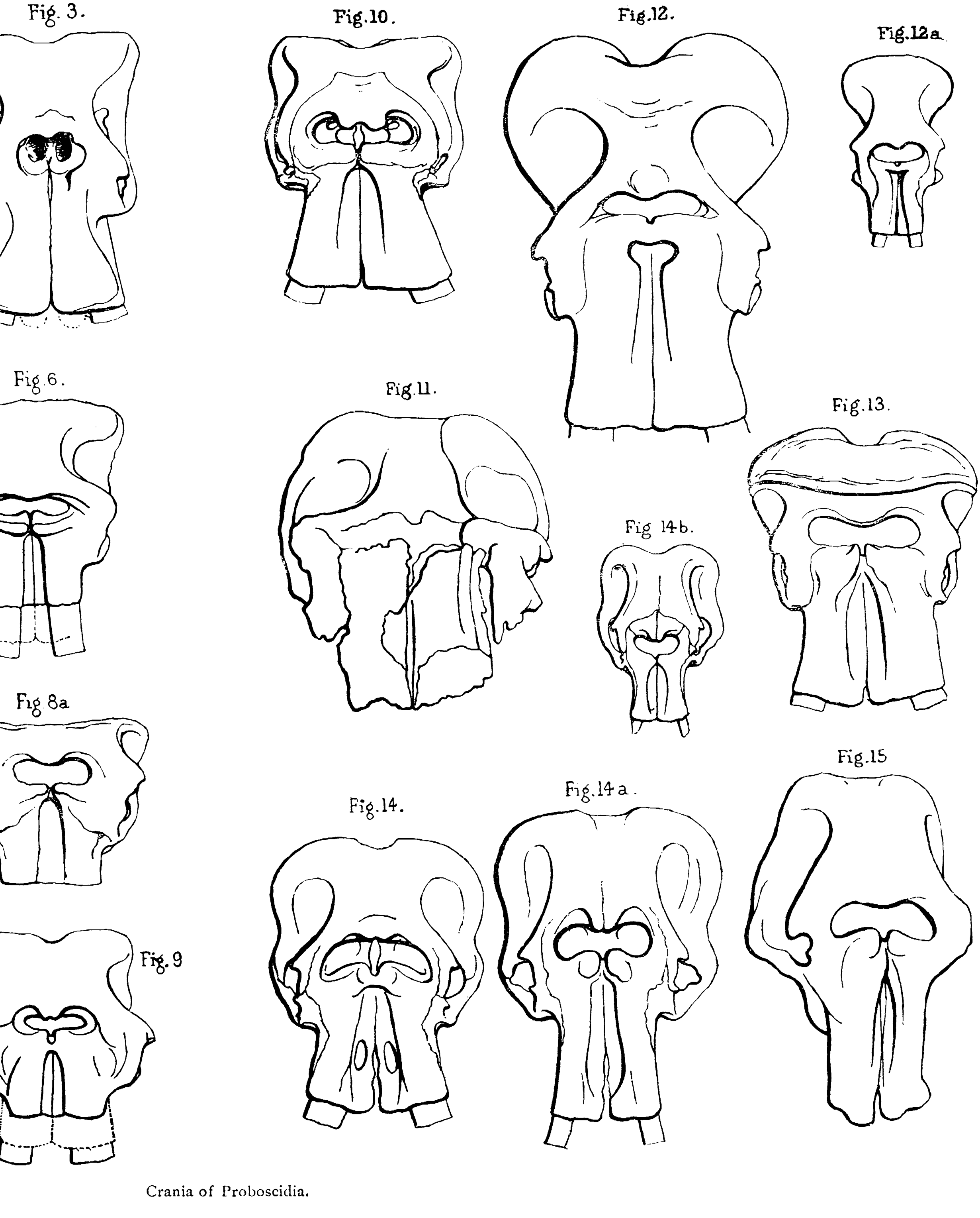
Bravais,[1] following in the steps of Delafosse and Franken-

[1] "Etudes cristallographiques." (Paris, 1866.)

PLATE XV.

Crania of Proboscidia.

PLATE XV.



Crania of Proboscidia.

heim, investigated the possible ways in which a system of points may be arranged in space so as to lie at equal distances along straight lines—in other words, so as to constitute what may be called a *solid network* (*assemblage*, *Raumgitter*).

The geometrical nature of a network may be best realized as follows: Take any pair (O C_1) of points in space, draw a straight line through them, and place points at equal distances along its entire length (C_2, C_3, . . .); such a line may be called a *thread* of points (*rangée*). Parallel to this line, and at any distance from it, place a second thread of points (A_1 a_1), identical with the first in all respects; in the plane containing these two threads place a series of similar equidistant parallel threads (A_2 a_2, &c.) in such positions that the points in successive threads lie at equal intervals upon straight lines whose direction (O A_1) is determined by the points upon the first two threads. Such a system of points lying in one plane may be called a *web* (*réseau*). Now, parallel to this plane, and at any distance from it, place a second web (B_1 b_1), identical with the first. Finally, parallel with these, place a series of similar equidistant webs in such positions that the points in successive planes lie at equal intervals upon straight lines whose direction (O B_1) is determined by the points in the first two webs.

In this way a *network* of points is constructed, in which the line joining any two points is a *thread*, and the plane through any three points is a *web*.

The space inclosed by six adjacent planes of the system, having no other points of the network between them is a parallelopiped (O A_1 B_1 C_1), from which the whole system may be constructed by repetition, and which may be taken to represent the structural element (*molécule soustractive*) of Haüy.

The complete investigation of all possible solid networks led Bravais to the conclusion that these, if classified by the character of their symmetry, fall into groups, which correspond exactly to the systems into which crystals are grouped in accordance with their symmetry.

It follows that two (not, however, independent) features of crystals are fully accounted for by a parallelopipedal arrange-

ment of points in space—namely, the symmetry of the crystallographic systems and the law which governs the inclinations of the faces (law of rational indices).

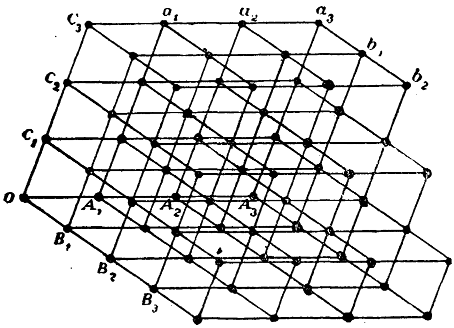


FIG 1

There are, however, subdivisions of the various systems consisting of the merohedral or partially symmetrical crystals belonging to them, which are not explained by the geometry of a network; these consequently were referred by Bravais, not merely to the arrangement of the molecules in space, but also to the internal symmetry of the molecule itself.

Hence the theory of Bravais, while able to a certain extent to explain the form of crystals, requires an auxiliary hypothesis if it is to explain those modifications which are partially symmetrical or merohedral.

Sohncke,[1] treating the problem in a different manner, and reasoning from the fact that the properties of a crystal are the same at any one point within its mass as at any other, but different along different directions, inquired in how many ways a system of points may be arranged in space so that the configuration of the system round any one point is precisely similar to that round any other. Such a configuration may be called a *Sohncke system* of points in space (*regelmässiges Punktsystem*).

From his analysis of this problem, it appears that there are

[1] "Entwickelung einer Theorie der Krystallstruktur." (Leipzig, 1879).

sixty-five possible Sohncke systems of points, and that these may be grouped according to their symmetry into six classes, corresponding to the six crystallographic systems; and further that there are within each class minor subdivisions, characterized by a partial symmetry corresponding to the hemihedral and tetartohedral forms of crystallographers.

The theory of Sohncke contains within itself the essential features of a Bravais network of structural molecules, and also the auxiliary hypothesis regarding the arrangement of parts within the molecules which is required to account for merohedrism. On close examination the arrangement of Sohncke proves to be a simple extension of that of Bravais.

Each of Sohncke's arrangements may be regarded as derived from one of the parallelopipedal networks of Bravais if for every point of the latter be substituted a group of symmetrically arranged satellites. It is not necessary that any particle in a group of these satellites should actually coincide with the point of the Bravais network from which the group is derived; and the points of the Sohncke system do not themselves form a network; it is only when all the points in each group of satellites are condensed into one centre that a Sohncke system coincides with a Bravais network.

To any particle of one of the satellite groups corresponds in every other group a particle similarly situated with regard to the point from which the group has been derived. Every such point may be said to be homologous with the first.

Each complete set of homologous points is itself a Bravais network in space, and consequently a Sohncke system may be regarded as a certain number of congruent networks interpenetrating one another: the number of such networks, in general, being equal to the number of points which constitute each group of satellites.

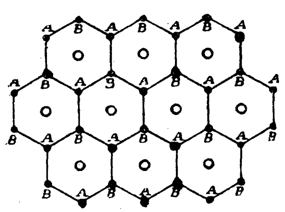


FIG 2.

The relation of a Sohncke system to the network from which it is derived may be illustrated by a bees'-cell distribution of points in one

plane, *i. e.*, by points which occupy the angles of a series of regular hexagons. Thus, in the adjoining figure the dots form a Sohncke system in one plane, since the configuration of the system round any one point is similar to that round any other; but they do not form a Bravais web, since the points do not lie at equal distances along straight lines.

If, however, points, represented in the figure by the circles O, be placed at the centres of the hexagons, they will by themselves constitute a web, and the hexagonal system may be derived from this web by replacing each of its points by a group of two satellites, A and B. Or, from the second point of view, the arrangement may be regarded as a triangular web, containing the points A, completely interpenetrated by a similar web, containing the points B.

It is a remarkable feature of the Sohncke systems that some among them are characterized by a spiral disposition of the particles along the threads of a right- or left-handed screw: now this spiral character, which does not belong to any of the Bravais networks, supplies a geometrical basis for the right- or left-handed nature of some merohedral crystals which possess the property of right- or left-handed rotary polarization.

The theory of Sohncke, as sketched above, appeared to be expressed in the most general form possible, and to include all conceivable varieties of crystalline symmetry.

It has, however, recently been pointed out by Wulff[1] that the partial symmetry of certain crystals belonging to the rhombohedral system—that, namely, of the minerals phenacite and dioptase—is not represented among the sixty-five arrangements of Sohncke.

Other systems of points in space have also been studied by Haag[2] and Wulff, which do not exactly possess the properties of a Sohncke system, and yet might reasonably be adopted as the basis of crystalline structure, since they lead to known crystalline forms.[3] These, however, and all other systems of

[1] *Zeitschr. f. Kryst.* xiii. (1887) p. 503.

[2] "Die regulären Krystallkörper." (Rottweil, 1887.)

[3] Cf. W. Barlow, *Nature*, xxix. (1884) pp. 186, 205.

points which have been proposed to account for the geometrical and physical properties of crystals, may be included in the theory of Sohncke after this has received the simple extension which is now added by its author.

In Bravais's network all the particles or structural elements were supposed to be identical, and in Sohncke's theory also there is nothing in their geometrical character to distinguish one particle from another.

In Fig. 2, the hexagonal series of dots may, as was said above, be regarded as composed of a pair of triangular webs, A and B; now these, although identical in other respects, are not parallel, for the distribution of the system round any point of A is not the same as that round any point of B until it has been rotated through an angle of 60°.

It is possible, however, to conceive similar interpenetrating networks which differ not only in their orientation but even in the character of their particles. The centre of each hexagon, for example, may be occupied by a particle of different nature from A and B to form a new web, O. The three webs are precisely similar in one respect, since their meshes are equal equilateral triangles; moreover, if the *position* of the points alone be taken into account, the whole system would form a Bravais web, *i. e.*, if the particles of O were identical with those of A and B. If, however, as is here supposed, the set O consists of particles different in character from A and B, the distribution round any point of O is totally distinct from that round any point of A or B. The points O are geometrically different from the points A B. The web A is interchangeable with B, but O is interchangeable with neither The interpenetrating networks are no longer to be regarded as consisting necessarily of identical particles, if an explanation is to be given of all the geometrical forms existing in nature.

The above figure represents a Sohncke system, A B, of particles of one sort interpenetrated by a Bravais web, O, of another sort; but there is no reason why two or more different Sohncke systems, no one of which is identical with a Bravais network, may not interpenetrate to form a crystal structure.

In its most general form, then, the theory may now be expressed—

A crystal consists of a finite number of interpenetrating Sohncke systems which are derived from the same Bravais network. The constituent Sohncke systems are in general not interchangeable, and the structural elements of one are not necessarily the same as those of another.

Or, since each Sohncke system consists itself of a set of interpenetrating networks, the theory may be thus expressed—

A crystal consists of a finite number of parallel interpenetrating congruent networks: the particles of any one network are parallel and interchangeable; these networks group themselves into a number of Sohncke systems in each of which the particles are interchangeable but not necessarily parallel.

The number of kinds of particles which constitute the crystal may therefore be equal to the number of Sohncke systems involved in its construction.

The structural units are no longer, as they were in the theory of Bravais, necessarily identical, but may represent atomatic groups of different nature.

The system in Fig. 2 consists of two sets of particles, A B and O; and, if a large enough number of these be taken, any portion of the system (*i. e.* any crystal constructed in this manner) consists of the particles united in the proportion of two of the first group to one of the second. Such an arrangement, then, may represent the structure of a compound, $O\ A_2$.

"When, for example, a salt in crystallizing takes up so-called water of crystallization which is only retained so long as the crystalline state endures, the chemical molecule salt + water cannot be said to exist except in the imagination, for the presence of such a molecule cannot be proved. To obtain an easily intelligible example, without, however, pronouncing any opinion as to whether it may be realized, imagine the centred hexagons in the figure to be constructed in such a way that each corner consists of the triple molecule $3\ H_2O$, and each centre consists of the molecule R. The chemical formula would then be $R + 6H_2O$, and yet a molecule of this constitution

would not really exist; on the contrary, the structural elements in the crystallized salt would be of two sorts—namely, R and $3H_2O$."[1]

Hence it is geometrically possible that the structural elements of a crystal may be different atomic groups which are held in a position of stable equilibrium by virtue of being interpenetrating networks.

A GENERAL PRELIMINARY DESCRIPTION OF THE DEVONIAN ROCKS OF IOWA; WHICH CONSTITUTE A TYPICAL SECTION OF THE DEVONIAN FORMATION OF THE INTERIOR CONTINENTAL AREA OF NORTH AMERICA.

BY CLEMENT L. WEBSTER.

The area of the Devonian rocks in North America presents at least four distinct types of stratigraphy in their sections, in different parts of the continent.

The four types blend, more or less, at their borders, but in their central area are quite distinct.

The four areas may be called,—

(1) "*The Eastern Border Area,*" including the outcrops of Gaspé, New Brunswick, Maine, and other places in Northern New England.

(2) "*The Eastern Continental Area,*" including the New York and Appalachian tracts as far South as West Virginia, and extending Northwestward into Canada West and Michigan.

(3) "*The Interior Continental Area,*" typically seen in Iowa, and extending into Missouri, Illinois, Indiana, and probably Northward toward the valley of the Mackenzie River, and—

(4) "*The Western Continental Area,*" best known through Hague and Walcott's studies of the Eureka, Nevada, sections.[2]

Each of these four types presents sections of the Devonian, which

1 Sohncke, *Zeitsch. f. Kryst.* xiv. p. 443.

2 This classification of (in part) Professor H. S. Williams (American Geologist, Special Number, October, 1888, p. 228) we here adopt, provisionally.